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FERTILIZERS FOR SUGAR BEETS ON SOME CALIFORNIA SOILS

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ERRATUM: Bulletin number in folio head should be 694 instead of 692.

FERTILIZERS FOR SUGAR BEETS ON SOME CALIFORNIA SOILS[1,2]

RAY A. PENDLETON[3] and W. W. ROBBINS[4]

SUGAR BEETS have been an important crop in California for many years, the first factory having been erected in 1870. At present about 175,000 acres are grown annually, and the beets are processed in eleven factories representing five sugar companies. The location of the principal acreage is discussed by Robbins and Price (*7*)[5].

Commercial fertilizers have been used to only a minor extent, except in recent years.

The Sugar Act of 1937, which included government payments for compliance with certain conditions of production, stimulated beet growers to increase their consumption of commercial fertilizers. This demand at once created a need for information on the fertilizers—the proper kinds, amounts, the methods of use, and other pertinent factors. In addition, opportunities were presented permitting fertilizers to be tried in the field on several important soil types. The present publication tabulates and interprets the information obtained from these experiments.

SOILS USED IN BEET PRODUCTION

Twenty-four counties in California have 500 acres or more each planted annually to sugar beets, and a few others have smaller acreages. From 50 to 60 soil types are represented in the 24 counties. Most of the production is confined, however, to a comparatively few of the deeper, more fertile soils of the valleys, including both mineral and organic (peat and muck) soils.

Certain soils are not adapted to sugar beets and should not be used for their culture. Being essentially a deep-rooted crop, beets are not adapted to soils with a pronounced hardpan or claypan. They are also not tolerant of acid soils. Arrhenius (*2*), who extensively surveyed the soils of Europe, found that those with a reaction of pH 7.0 to 7.5 were most favorable for beets; growth was good at pH 8.3, but very poor on acid soils. Field tests in the Sacramento Valley, made by a colorimetric method, indicate that soils more acid than pH 5.5 are somewhat hazardous for beets, with usually complete failure at pH 5.0. Good growth has been noted on Panoche clay loam that tested pH 8.5.

The soils used in the experimental work reported below include Yolo loam, Sacramento clay loam, Sacramento clay, Columbia loam, Conejo loam, Ryde clay loam, Egbert muck, and Staten peaty muck. These include both mineral and organic soils and range from acid to slightly alkaline in reaction. In other areas of California, soils extensively used in beet production, such as those of

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[2] The work reported herein was conducted as a joint coöperative project between the Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture, and the California Agricultural Experiment Station, at Davis, California, through its Botany Division.

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[5] Italic numbers in parentheses refer to "Literature Cited" at the end of this bulletin.

the Chino, Metz, Sorrento, and Salinas series, are more alkaline, distinctly calcareous, and in their fertilizer response, especially with respect to phosphorus, may differ from still other areas in the state.

FERTILIZERS USED IN BEET PRODUCTION

Fertilizers are concentrated forms of plant nutrient materials. They may be obtained as mineral salts or as organic matter in animal by-products, barnyard manures, fish meal, and the like. These same or similar mineral or organic nutrients occur in soils, but often in deficient quantity, at least with respect to one or more elements. Fertilizers are classified and sold on the basis of their plant food content given in percentage composition. They may be straight goods containing only one plant food material, or complete fertilizers containing two or more kinds.

Nitrogen, phosphorus, and potassium are the fertilizer elements used in greatest quantity in sugar-beet production. Nitrogen, the one most frequently deficient in California soils, is placed on the market in several forms, including ammonium sulfate, ammonium nitrate, sodium nitrate, calcium nitrate (also called nitrate of lime), urea, calcium cyanamide, ammonia gas, and in combination with phosphate as ammonium phosphate.[6] In the work reported here, Cal-Nitro was also used. The percentage of nitrogen varies in the different materials—a fact one should bear in mind when selecting a fertilizer.

Phosphorus is marketed as superphosphate, treble phosphate, ammonium phosphate (in various combinations), basic slag, and other products. The main potassium salts are potassium sulfate and muriate of potash. All three elements are contained in varying amounts, in organic fertilizers and manures. So-called "complete" fertilizers containing these three elements are marketed in various combinations. Thus an 8–10–12 fertilizer contains 8 per cent nitrogen (N), 10 per cent phosphoric acid (P_2O_5), and 12 per cent potash (K_2O).

The selection of the proper kind of fertilizer is of great importance; the grower should be guided by the soil type and conditions under which the material is to be used, the results of plot tests, and experience gained in the same locality.

Manures and composts supply to soils not only valuable plant food materials, but also organic matter, which is much needed on most of the mineral soils in northern California. Barnyard manures, according to average figures, contain 10 to 15 pounds of nitrogen, 5 to 7 pounds of phosphoric acid and 7 to 15 pounds of potash per ton. The value of manure has been variously estimated at from $1.00 to $5.00 per ton, according to the crop conditions under which it is used. Good artificial manures may be made by composting straw, hay, weeds, and other plant residues (*5*).

Besides the three common plant food elements listed above, several other elements are required by plants. Calcium, magnesium, and sulfur are used in substantial amounts, but are not generally deficient in the soils of northern California commonly used for beet production. Others are used in very small amounts and are usually referred to as minor or micro elements. They include

[6] Ammo-Phos B, a fertilizer containing 16 per cent nitrogen and 20 per cent phosphoric acid was used as the source of the ammonium phosphate mentioned herein. Other similar materials, however, could be substituted.

such materials as boron, zinc, manganese, iron, and copper. In general, they are present in sufficient quantity in the soil, and they are also frequently present as impurities in other fertilizers.

DETERMINING THE FERTILIZER REQUIREMENTS OF SUGAR BEETS

The ultimate objective in applying fertilizers is to increase crop yields. Although the amount of plant food materials used by a crop can be readily calculated, this information is of little value in determining the fertilizer needs of a soil.

The amount of nitrogen used by a crop varies with the available supply. Studies of beets from six fields in the Sacramento Valley in 1939 on soils of high fertility showed a nitrogen content in the roots of 1.20 per cent dry weight, whereas on soils of low fertility the roots had 0.60 per cent nitrogen. The nitrogen content of the leaves is frequently about double that of the roots. According to Gardner and Robertson (*4*), beets remove 2½ to 4 pounds of nitrogen from the soil per ton of roots and 4 to 5 pounds of nitrogen in the tops from a ton of roots. Beets remove about half as much phosphorus as nitrogen and about the same quantity of potassium as of nitrogen. The phosphorus and potash content is more constant than the nitrogen.

The amount of these materials in a crop is, however, of very little significance in determining the amount necessary to increase yields but it may suggest what elements are limiting. Soils deficient in one material may have a great excess of others. Some method of testing and experimentation is necessary to evaluate the soil needs.

With any crop the efficient use of fertilizers depends on careful attention to four points: (a) kind of material, (b) time of application, (c) placement of the material with respect to the plant roots, and (d) rate of application. Neglect of any one of these factors may nullify the results, thus causing the grower to be misled.

Soils men have long been interested in determining the fertilizer needs of a soil for crop plants. The problem is not a simple one. Although many methods have been devised, all are subject to limitations. Methods may be generally grouped as quick or rapid chemical tests, biological soil tests, plant tests, pot tests, and field trials. The reliability of these various types and kinds of tests has been discussed by Anderson and Noble (*1*), Schreiner and Anderson (*8*), and Hoagland (*6*). Field trials properly conducted are the most accurate, but are necessarily time consuming. The more rapid chemical and biological tests are sometimes useful as short cuts in setting up field trials, but alone are usually inadequate and may be misleading. Probably the most satisfactory system of soil testing is a combination of several methods. In the work here reported, rapid chemical tests and pot tests were used as preliminary to field trials.

EXPERIMENTAL WORK AND RESULTS

After preliminary chemical and pot tests, field experiments were initiated in various localities on important soil types. In addition, some greenhouse investigations were made regarding the effect of fertilizers on germination

of seed. The field trials were not uniform in all cases, but were designed to fit the circumstances prevailing. Plots were usually made in strips of 16 rows of beets the full length of the field to facilitate harvesting, although a few plots were about 400 feet long, yielding about one truck load each, and circumstances sometimes necessitated small plots of about $\frac{1}{50}$ acre or less for hand-harvesting. Plots were mainly arranged in a randomized block system with three to six replications, although in a few trials the Latin-square system was used. The larger plots were harvested completely in the usual commercial manner, with dump weights accepted for harvest records, and with sugar-company analyses taken for sucrose determinations. In single-load or smaller plots, extra samples were selected for sucrose determinations in order to have at least three determinations for each plot.

A large number of field trials were made during the course of this study. It is impracticable to tabulate the results from all of them; therefore, a few of the trials best representing the soils under investigation have been selected. However, some consideration has been given to all trials in arriving at general conclusions.

In designing field experiments on the effect of fertilizers, the factors that might possibly affect the results are usually too numerous to be included in any one trial. In the experiments on mineral soils, herein reported, only a few of the basic factors were included.

Sugar beets are a relatively deep-rooted crop, and in northern California soils the need for fertilizer is most apparent after the plants are well established. Experience has shown that one of the most satisfactory methods of application is to side dress with a fertilizer drill at about thinning time, placing the fertilizer 5 to 7 inches deep, sufficiently distant from the row to avoid root injury.

There are several points in favor of placement at thinning time. A stand of beets is thus reasonably well assured, and the young plants to be removed in thinning will not have utilized the applied fertilizer elements. The beet roots, furthermore, have penetrated sufficiently into the soil so that fertilizers placed at a distance of 6 inches or farther to one side of the row will be quickly accessible. In most of this experimental work, accordingly, the initial application of fertilizer was made about thinning time.

Under some conditions of planting, other types of placement may be desirable and satisfactory.

Comparisons were made between different forms of nitrogen, between different amounts or rates of application, and between phosphate and complete fertilizer mixtures and with nitrogen alone. Results were analyzed, according to the analysis-of-variance method as described by Snedecor (*9*), for yield, sucrose percentage of the beets, gross sugar produced, and in some instances apparent purity coefficient.

EFFECT OF FERTILIZERS ON GERMINATION

Judging from field observations at various times, certain fertilizers, particularly nitrogenous, when placed in contact or near the seed will seriously reduce stands. To investigate this situation further, a quantity of Yolo loam soil was placed in a greenhouse bed about 6 inches deep. Beet seed was planted

in this soil under various fertilizer treatments, the material being placed either in contact with or at specified distances from the seed and with two depths of planting. The effects of the treatments on germination, where the fertilizers were placed in contact with the seed, are summarized in table 1.

In a second experiment, only one depth of planting with two different rates of application was used, and counts were made on three different dates. In the first trial (table 1), the fertilizers were applied on a basis of a uniform rate

TABLE 1

Germination Tests with Fertilizer Applied Directly with the Seed

Fertilizer	Seedlings per 100 seed balls at the planting depths given							
	After 12 days		After 15 days		After 25 days		After 35 days	
	At 1½ inches	At 2½ inches	At 1½ inches	At 2½ inches	At 1½ inches	At 2½ inches	At 1½ inches	At 2½ inches
Fertilizer at rate of 150 pounds per acre applied in row with seed								
Superphosphate	49	18	79	24	123	28	138	28
Treble superphosphate	24	10	57	26	113	39	118	40
Ammonium phosphate (16–20–0)	15	1	19	1	53	12	91	21
Ammonium sulfate	4	0	5	5	17	9	23	9
Calcium nitrate	4	0	5	5	42	13	77	13
Untreated soil	82	21	95	24	111	26	118	26
Fertilizer at rate of 300 pounds per acre applied in row with seed								
Superphosphate	6	3	27	7	78	23	83	31
Treble superphosphate	9	2	23	4	69	22	75	37
Ammonium phosphate (16–20–0)	0	1	0	1	11	11	22	23
Ammonium sulfate	0	0	1	0	10	0	12	0
Calcium nitrate	0	0	0	0	1	11	12	21
Untreated soil	82	21	95	24	111	26	118	26

of material per acre, disregarding the amount of plant food contained in them, whereas in the second trial the fertilizers were applied on a basis of a uniform amount of plant food material.

These results, although having considerable irregularity because of moisture variations in the soil under the different trials, show clearly the injurious effect of nitrogenous fertilizers on germination. This effect is greater when the fertilizer comes in direct contact with the seed, but is also highly hazardous when the fertilizer is separated by an inch of soil. Results similar to those listed in table 2 were obtained in another trial (for which complete data are not given), in which the fertilizer was placed on the same level with the seed but 1 inch to the side. At heavy rates of treatment there was almost 100 per cent injury with nitrogen-carrying material. The 2½-inch planting depth in itself was a definite hazard to germination, showing less than 30 per cent of the stand compared with 1½-inch planting depth. The delay or prevention of germination because of fertilizer application was concluded to be largely a moisture-limiting factor. Seed balls removed, after 2 or 3 weeks, from prox-

imity to the fertilizers and placed in fresh soil with plenty of moisture still showed satisfactory germination, indicating that the germ had not been seriously damaged.

FIELD EXPERIMENTS WITH FOUR MINERAL SOILS

In the Sacramento Valley four of the most important series of mineral soils used for sugar beets are the Yolo, Sacramento, Columbia, and Conejo.

SOILS OF THE YOLO SERIES

Soils of the Yolo series probably represent the largest acreage used for sugar beets in the Sacramento Valley. They occur also in several of the coastal valleys in central and southern California. These soils occupy gently sloping

TABLE 2
Germination Tests with Fertilizer Placed 1 Inch below the Seed with the Seed at a Uniform Depth of 1½ Inches

Treatment	Seedlings per 100 seed balls		
	After 7 days	After 12 days	After 16 days
Fertilizer placed 1 inch below seed at the rate of 50 pounds plant food material			
Superphosphate	...	120	135
Treble superphosphate	100	150	151
Ammonium phosphate (16–20–0)	31	74	104
Ammonium sulfate	18	50	89
Calcium nitrate	2	3	22
Untreated soil	87	130	134
Fertilizer placed 1 inch below seed at the rate of 100 pounds plant food material			
Superphosphate	101	169	175
Treble superphosphate	129	164	170
Ammonium phosphate (16–20–0)	56	120	146
Ammonium sulfate	23	55	61
Calcium nitrate	14	23	26
Untreated soil	138	164	164

recent alluvial fans or valley floors, and are stream deposits from sandstone and shale parent material. They are typically brown in color, noncalcareous, and neutral to slightly acid in reaction. These soils are deep, well drained, naturally fertile, and very productive. Often, however, they are run-down and unproductive because of mismanagement.

Yolo Loam under Low Fertility Conditions.—In this experiment, beets in the field were showing pronounced symptoms of nitrogen starvation before the fertilizer treatment was made. Because of the lateness of the season before the treatment, only a nitrate form of nitrogen was considered—namely, calcium nitrate, used in two rates of application, on plots about 2 acres each in area, replicated three times. Applications were made as side dressings 6 inches deep, followed immediately by an irrigation. Table 3 gives the results.

In this very low-yielding field of Yolo loam, the effect of the treatments

was striking, with the greatest difference coming from the first 40-pound increment. The fertilizers had no effect on the sucrose percentage.

Yolo Loam under Medium Fertility Conditions.—In an experiment on Yolo loam of medium fertility, four forms of nitrogen were tried in two different rates. In one of these trials a combination treatment was arranged,

TABLE 3

RESULTS FROM CALCIUM NITRATE TREATMENTS ON YOLO LOAM OF LOW FERTILITY, 1939

Treatment	Nitrogen rate per acre*	Gross sugar per acre	Beets per acre	Sucrose
	pounds	*pounds*	*tons*	*per cent*
Calcium nitrate	40	5,122	13.40	19.11
Calcium nitrate	80	5,563	14.47	19.36
Untreated soil	..	3,667	9.54	19.26
Difference between treatments required for significance†	..	1,083	3.42	2.20

* The number of pounds of fertilizer per acre required to supply the number of pounds of plant food at the rate indicated can be calculated from the formula: Pounds fertilizer per acre $= \frac{\text{pounds plant food per acre} \times 100}{\text{per cent plant food in fertilizer}}$.

† A difference between treatments as large as the one indicated would be significant in 19 out of 20 cases (5 per cent level).

TABLE 4

RESULTS FROM VARIOUS NITROGEN FERTILIZERS ON YOLO LOAM OF MEDIUM FERTILITY, 1940

Treatment	Nitrogen rate per acre*	Gross sugar per acre	Beets per acre	Sucrose
	pounds	*pounds*	*tons*	*per cent*
Urea	50	8,201	20.50	20.00
Ammonium sulfate	50	8,409	21.53	19.55
Cal-Nitro	50	8,151	20.19	20.20
Cal-Nitro	100	9,020	23.35	19.32
Urea (May 1)	50	9,553	25.24	18.90
Sodium nitrate (June 28)	50			
Untreated soil	..	6,492	16.37	19.84
Difference between treatments required for significance*	..	629	1.75	0.71

* See footnotes to table 3.

with half the fertilizer applied at thinning time, May 1, and the other half on June 28. Three replications of each treatment were made with plots of about 1 acre each. Table 4 gives the results.

Several significant facts are evident from these data. An increase in tonnage is noted for all treatments, the tonnage data falling into four groups. In the lowest group is the untreated soil. Above this is the soil treated with 50 pounds of nitrogen. The form of nitrogen, as will be noted, did not seem to influence the results. Significantly, above the 50-pound group is the group receiving 100 pounds of nitrogen in one application, and above that is the fourth group in which the same rate of 100 pounds of nitrogen was divided into two applications.

Cal-Nitro, which has about half its nitrogen in the nitrate form, showed no advantage over the other forms; it is suggested, therefore, that the added

effect of the divided treatment was attributable to the delayed application of a portion of it. Treatment effects on yield of gross sugar per acre fall into the same groups as the tonnage yields.

Neither the 50-pound nor the 100-pound rate of nitrogen when applied all at once had any appreciable effect on sucrose percentage. The divided treatment, however, depressed the sucrose nearly 1.00 per cent, a figure that is definitely significant, indicating delayed maturity under this treatment. Purity determinations on samples from these treatments showed a range of variations of only 0.34 per cent—from 88.60 in the lowest to 88.94 in the highest. We conclude, accordingly, that the fertilizers did not affect purity.

Of importance here is the fact that the untreated yield was 16 + tons per acre. This soil, although in more fertile condition than that used in the previous experiment, has a potential yielding value somewhat higher than 16 tons, as shown by adjoining fields; evidently, then, it was in a state of only medium fertility, its nitrogen having been depleted.

TABLE 5

RESULTS FROM AMMONIUM SULFATE ON YOLO LOAM OF HIGH FERTILITY LEVEL, 1940

Treatment	Nitrogen rate per acre*	Gross sugar per acre	Beets per acre	Sucrose
	pounds	*pounds*	*tons*	*per cent*
Ammonium sulfate	50	11,050	30.22	18.25
Ammonium sulfate	100	10,643	29.92	17.78
Untreated soil	..	9,998	26.92	18.61
Difference between treatments required for significance*	..	1,586	3.42	1.26

* See footnotes to table 3.

Of importance, also, was the fact that the fertilizers were applied only in alternate row spaces. Although this method was not directly compared with placement in all row spaces, the results indicate that it was generally successful.

Yolo Loam under Relatively High Fertility Conditions.—In this field a volunteer covercrop consisting mainly of bur-clover and weeds had been turned under early in 1939, after which the soil was kept fallow until the planting of the 1940 beet crop. The fertilizers were applied as side dressings on April 30, by the same method as used in the previously mentioned experiment—placement only in alternate row spaces. Since the fertility level was assumed to be high, only one form of nitrogen was used in two rates. Plots, about 1 acre each in size, were replicated three times. The results appear in table 5.

Of particular interest here is the fact that the untreated beets yielded 26 + tons per acre. Although a slight increase in yield resulted from the fertilizers, it was as great from the 50-pound as from the 100-pound rate, and neither rate was statistically significant under the conditions of the experiment. Likewise, there was a trend toward a depression in sucrose percentage; but again it was not significant.

The Effect of a Luxury Supply of Nitrogen on Yolo Loam.—Frequently growers have asked what constitutes a luxury supply of nitrogen and how it

would affect sugar-beet yields. Since in ordinary field trials, like those cited, the large size of plots prohibits the inclusion of tests with extremely high amounts of fertilizer, because of excessive costs, a small-scale experiment was conducted in 1940 on Yolo loam. Urea fertilizer was tested in four rates on plots $\frac{1}{50}$ acre in size, replicated five times in Latin-square arrangement. Application was made midway between rows about 6 inches deep at thinning time. The results appear in table 6.

Because of wide differences between individual plot yields of like treatments in this experiment, the standard error here was very high, and the increased tonnage of beets produced was not significant. Likewise there was no significant increase in the production of sugar per acre. The experiment

TABLE 6
Results of Luxury Applications of Nitrogen on Yolo Loam of High Fertility Level, 1940

Treatment	Nitrogen rate per acre*	Gross sugar per acre	Beets per acre	Sucrose
	pounds	*pounds*	*tons*	*per cent*
Urea	100	9,734	26.54	18.32
Urea	200	9,672	27.31	17.67
Urea	300	8,711	26.29	16.59
Urea	400	8,996	28.97	15.53
Untreated soil	...	8,762	23.55	18.60
Difference between treatments required for significance*	...	1,356	3.79	0.80

* See footnotes to table 3.

was on soil of relatively high fertility, as shown by the 23.5 tons yield on the untreated plots. The results, therefore, are not a measure of what would occur on soils of low fertility.

Of particular interest is the pronounced and highly significant depression in sucrose percentage, which was in direct proportion to the amount of nitrogen applied. The apparent purity, not shown in table 6, was likewise significantly reduced in proportion to the amount of nitrogen applied in treatments. The untreated plots showed a purity value of 88.37 per cent, and the highest nitrogen plots 82.93 per cent. Apparently, therefore, under this soil condition extremely heavy nitrogen treatments might be definitely detrimental.

When one summarizes the results of the four experiments listed above for Yolo loam, it becomes apparent that wide differences exist in yielding ability of different fields of this soil type—differences probably occasioned chiefly by variations of the nitrogen supply through loss or addition of soil organic matter. This variation represents differences in cropping practices during the preceding years.

Where the soil nitrogen has been depleted, it may profitably be replaced with commercial forms of nitrogen until it can be renewed by the slower process of replenishing the supply of organic matter in the soil. When fertility levels are very low, as much as 150 pounds of nitrogen per acre may be used economically. Where such amounts are needed, a good fertilizer practice would apparently require dividing the application into two approximately

equal parts, the first to be applied about thinning time and the second during the period of most vigorous vegetative growth. Where the fertility level is such that the untreated yields of beets run about 15 to 20 tons per acre on this soil, 100 pounds of nitrogen per acre is apparently all that can be economically used; and with untreated yields at 20 to 25 tons per acre, no more than 50 pounds of nitrogen per acre produced significant results. Where the soil has been improved with cultural practices to a yielding capacity of 25 to 30 tons per acre, there seems to be considerable question regarding the value of any commercial nitrogen. In all cases, as the supply of nitrogen was increased, the sucrose percentage decreased; and where excessive amounts were applied, the depression in sucrose overbalanced the yield increases until no increase in gross sugar was produced. The form in which the nitrogen was supplied made no noticeable difference.

Results with Phosphate and Potash.—In the trials listed above there was no investigation of the effect of potash or phosphate on this soil. In other trials of Yolo loam and Yolo clay loam, however, tests with these materials have been included. In 1938 a complete fertilizer of 11–11–11 analysis was applied in varying rates up to 2,000 pounds per acre (220 pounds of nitrogen) on small plots on Yolo clay loam. Small but nonsignificant increases in yield were obtained. In this same trial calcium nitrate at a rate to supply 200 pounds of nitrogen per acre increased the weight per beet from 1.025 to 1.530 pounds, where a significant difference was 0.343 pounds per beet. In no case was any significant added benefit secured from using phosphate or potash alone or in connection with nitrogen on soils of the Yolo series.

SOILS OF THE SACRAMENTO SERIES

Probably the second most important sugar-beet soil in the Sacramento Valley, based on acreage, is the Sacramento series, represented mainly by Sacramento clay and clay loam.

The Sacramento soils occur in nearly flat basins or on valley floors and under natural conditions are subject to high water table and frequent flooding. They are usually heavy-textured and range from slightly acid to slightly alkaline in reaction. These soils are naturally very productive; but in many fields mismanagement has caused a loss of organic matter and the development of a plow sole, which has resulted in low productivity.

Several field experiments were conducted on these soil types during the years 1935 to 1940. Illustrative of the effects was a field trial in 1939 on Sacramento clay loam, which included two forms of nitrogen in two rates as well as one complete fertilizer mixture. Plots were made about 1½ acres each in size and were replicated three times. The results appear in table 7.

Appreciable increases in yield resulted from the straight nitrogen treatments. The tonnage increase was proportional to the amount of nitrogen used. Cal-Nitro showed indications of being slightly superior to the ammonia form of nitrogen although further trials would be necessary to definitely determine this. In common with other similar treatments, there was a slight depression in sucrose percentage, which was also proportional to the amount of nitrogen in the fertilizer. As with other field results, no added benefit was derived from including phosphate or potash with nitrogen under the condition obtaining.

On another field of Sacramento clay, where the untreated yield was about 33 tons per acre in 1939, treatments similar to those cited above gave no increase in yield. In this field where the natural fertility was high enough so that no increased yield was obtained from the addition of 100 pounds of nitro-

TABLE 7
Results from Nitrogen and Complete Fertilizers on Sacramento Clay Loam of Medium Fertility Level, 1939

Treatment	Rate per acre*			Gross sugar per acre	Beets per acre	Sucrose
	N	P_2O_5	K_2O			
	pounds	*pounds*	*pounds*	*pounds*	*tons*	*per cent*
Cal-Nitro	100	..	..	8,391	22.62	18.59
Ammonium sulfate	100	..	..	8,520	21.87	19.47
Cal-Nitro	50	..	..	8,542	20.76	20.60
Complete fertilizer	50	60	50	7,240	18.66	19.36
Untreated soil	..	..	..	7,631	18.47	20.70
Difference between treatments required for significance*	..	..	..	990	3.39	1.04

* See footnotes to table 3.

TABLE 8
Results from Nitrogen and Phosphate Applications on Sacramento Clay of Medium Fertility Level, 1940

Treatment	Rate per acre*		Gross sugar per acre	Beets per acre	Sucrose
	N	P_2O_5			
	pounds	*pounds*	*pounds*	*tons*	*per cent*
Treble superphosphate	0	75	6,966	17.85	19.36
Cal-Nitro	50	0	7,765	20.80	18.44
Sodium nitrate	50	0	7,684	20.59	18.70
Ammonium phosphate (16–20–0)	32	40	7,688	20.15	18.60
Sodium nitrate	100	0	8,088	23.07	17.73
Untreated soil	..	..	6,954	17.94	19.10
Difference between treatments required for significance*	..	..	1,287	3.74	0.74

* See footnotes to table 3.

gen per acre, a complete fertilizer in mixture of 10–12–10 analysis and supplying 60 pounds per acre of P_2O_5 likewise gave no increase in yield. This effect agreed with results secured on soils of the Yolo series.

In 1940 a trial on Sacramento clay was made using three sources of nitrogen and one of phosphate, each in two rates. Plots were made about 1 acre each in size and were replicated three times. The results appear in table 8.

Under the conditions of this experiment only the heaviest rate of nitrogen appreciably increased the yield. Because of the definite depression in sucrose produced by this same treatment, however, there was only a small increase in gross sugar per acre. There was a tendency for yields to be somewhat increased by the lower rates of nitrogen, but no effect from the phosphorus either alone or with nitrogen. Since the untreated soil showed a fairly good yield, there was evidently no marked nitrogen deficiency.

SOILS OF THE COLUMBIA SERIES

The Columbia soils constitute probably the third most important series used for sugar-beet growing in the Sacramento Valley. They occur adjacent to the Sacramento River and are lighter textured and better drained than the Sacramento soils. These soils are noncalcareous and neutral to slightly alkaline in reaction. They are naturally fertile; but, like the Yolo and Sacramento soils, they vary widely in productivity because of previous cropping history and management.

TABLE 9

Results from Different Forms and Amounts of Nitrogen and from Certain Mixtures on Columbia Loam, 1939

Treatment	Rate per acre*			Gross sugar per acre	Beets per acre	Sucrose
	N	P_2O_5	K_2O			
	pounds	*pounds*	*pounds*	*pounds*	*tons*	*per cent*
Ammonium sulfate	40	0	0	6,337	16.83	18.73
Ammonium sulfate	80	0	0	7,142	18.56	19.01
Ammonium sulfate	120	0	0	7,268	19.77	18.40
Calcium nitrate	40	0	0	7,038	18.54	18.79
Calcium nitrate	80	0	0	6,817	18.47	18.36
Calcium nitrate	120	0	0	7,437	21.30	17.25
Ammonium phosphate (16–20–0)	45	56	0	6,084	16.24	18.62
Complete fertilizer	40	30	30	6,280	17.06	18.15
Untreated soil	..	..	..	5,196	12.90	20.17
Difference between treatments required for significance*	..	..	..	1,046	2.39	1.72

* See footnotes to table 3.

A number of trials have been conducted upon the Columbia loam, one of the dominant types of the series, some fields having given low yields and some relatively high yields. A trial in the Sutter Basin district in 1939 using a complete fertilizer, ammonium phosphate (16–20–0), and two forms of nitrogen applied at three rates each will serve to illustrate the effects of these fertilizers on a medium-low-yielding field. Plots for this experiment were about ¼ acre in size and were replicated six times. The results appear in table 9.

All of the treatments definitely increased the tonnage of beets and the yield of gross sugar per acre. The 40-pound rate of nitrogen in the ammonium sulfate, the ammonium phosphate, and the complete fertilizer all appeared to be about equal in effect, producing an increase of about 3.75 tons of beets and 1,025 pounds of gross sugar per acre. The 80 pounds of nitrogen in ammonium sulfate and both the 40- and the 80-pound rate in calcium nitrate tended to form a higher group, having about 5.75 tons' increase in beets with a corresponding increase in gross sugar. The two heaviest rates of nitrogen produced still greater effects, with about 7.75 tons' increase in beets and a further increase in gross sugar. Apparently, then, the first increment of 40 pounds of nitrogen gave an increased tonnage of 3.75, and each of the second two increments of 40 pounds apiece gave 2.00 tons of additional yield.

All of the treatments tended to depress sucrose percentage—somewhat in proportion to the amount of nitrogen used. This effect became significant in

the highest rate of ammonium sulfate, in the two higher rates of calcium nitrate, and in the complete fertilizer. The effect of the complete fertilizer mixture was somewhat out of line with the other treatments in this respect. A similar effect was noted on Sacramento clay soil (table 7) with a similar fertilizer mixture.

Under the conditions of this experiment, the nitrate form of fertilizer seemed to have a slight advantage over the ammonia form. In another trial on Columbia loam, however, this preference was not shown. In that trial, for which the data are not tabulated, 50 pounds of nitrogen in ammonia, or nitrate, or urea form gave an average increase of 4.25 tons of beets per acre, with an average loss of 0.65 per cent in sucrose. The 120-pound rate of nitrogen increased the yield 9.5 tons per acre, with nearly 3,000 pounds gross sugar increase. In that field the untreated yield was about 12 tons per acre.

Under another field condition on Columbia loam, the untreated yield was 23 tons per acre; and the yield was not appreciably increased by any form of nitrogen tried in rates of 50, 75, and 100 pounds.

The Columbia soils appear to have a slightly lower productivity for sugar beets than soils of the Yolo or Sacramento series. They do show the same tendency, however, in that their response to nitrogen fertilizer is determined mainly by the degree to which the soil has been permitted to deteriorate. Where a high state of fertility has been maintained by cropping practice, no profitable returns can be secured from commercial nitrogen fertilizers; but where the organic matter supply has been depleted and the nitrogen allowed to become deficient, as much as 120 pounds of nitrogen per acre may profitably be used. As with the soils previously discussed, there is no evidence that either phosphorus or potash is of any value for sugar beets on Columbia loam.

SOILS OF THE CONEJO SERIES

Soils of the Conejo, Farwell, Vina, and Nord series in the upper Sacramento Valley are used to a limited extent for sugar-beet production. The Conejo soils occur on nearly level lower edges of alluvial fans and on margins of basin areas. In some respects they resemble the Sacramento soils; but they were developed under better drainage conditions. They are neutral to slightly alkaline in reaction and generally fine-textured.

For an experiment in 1939, a field was selected on Conejo loam that had been cropped to beans the previous year. Seven fertilizer treatments were made, using four forms of nitrogen and one complete fertilizer. Plots were made about ¼ acre in size and were replicated six times. The results appear in table 10.

Because of previous cultural conditions, this field was in a state of relatively high fertility, as was shown by the almost 20-ton yield of untreated beets. All fertilizer treatments, regardless of kind or rate, showed highly significant increases in both tonnage yield and gross sugar. Judging from the uniformity of increase from all treatments, only the first increment of 50 pounds of nitrogen was effective. The average increase in yield, 3.9 tons per acre, is quite in line with similar results on the other soils. Of interest in this experiment is the fact that the sucrose percentage did not decrease.

In common with the other mineral soils discussed, there is no evidence that

phosphate or potash was effective in increasing yields. Determinations of the coefficient of apparent purity made for the various treatments are not given in detail. A significant reduction in purity was shown, however, for the heavy rates of nitrogen as sodium nitrate, calcium nitrate, and ammonium sulfate.

According to field observations, the nitrate fertilizers produced their peak effect about the middle of June, whereas the peak effect of the ammonia and urea fertilizers was not evident until about the middle of July. This feature might be of considerable importance if early harvest were contemplated. Since in this instance the harvest was rather late, there was no essential difference in the final results.

TABLE 10

Results from Different Forms and Amounts of Nitrogen and a Complete Fertilizer on Conejo Loam, 1939

Treatment	Rate per acre*			Gross sugar per acre	Beets per acre	Sucrose
	N	P_2O_5	K_2O			
	pounds	*pounds*	*pounds*	*pounds*	*tons*	*per cent*
Urea	50	0	0	7,982	23.18	17.32
Ammonium sulfate	100	0	0	8,374	24.14	17.35
Calcium nitrate	50	0	0	8,359	23.60	17.79
Calcium nitrate	100	0	0	8,449	24.42	17.42
Sodium nitrate	100	0	0	7,995	23.73	16.87
Urea	100	0	0	8,273	24.04	17.29
Complete fertilizer	30	40	30	8,052	22.92	17.58
Untreated soil	..	..	..	6,969	19.81	17.72
Difference between treatments required for significance*	..	..	..	697	3.25	1.00

* See footnotes to table 3.

Another field of Conejo loam, cropped to milo in 1938 and to beets in 1939, gave similar results; the data, however, have not been tabulated. In this case, possibly because of the deleterious effects of the milo residue, the yield of beets from the untreated plots was 14.58 tons per acre. Fifty pounds of nitrogen produced about 4.0 tons' increase in yield, and the second increment of 50 pounds in the heavier rate gave some additional return, although not one that was significantly higher. No appreciable difference was shown as to form of nitrogen, and there was no appreciable effect on either sucrose percentage or purity.

SUMMARY RELATIVE TO MINERAL SOILS

In summarizing the results secured on the Yolo, Sacramento, Columbia, and Conejo soils, one notices a few facts that seem common to all. Neither phosphate nor potash was of benefit either alone or with nitrogen in any of the trials. In only a few instances was there evidence of any appreciable difference in the form of nitrogen used. Where a difference was shown, the nitrate form was a little more effective in increasing tonnage yield; likewise, it showed a slightly greater tendency to depress sucrose and purity.

Usually the first increment of 50 pounds of nitrogen produced 3.5 to 4 tons' increase in yield. The need for a second increment of nitrogen was determined by the natural fertility level of the soil. If the fertility level was low, a second

50 pounds of nitrogen usually produced an additional 2 to 3 tons of increased yield; and if the fertility level was markedly low, a third increment of 50 pounds of nitrogen might give still another 2 tons of increased yield. Where the natural fertility was very high, no fertilizer was effective. This upper limit varies for different soils and does not necessarily represent the ultimate in yield that may be produced from a given soil. As is well known, yields of 30 to 35 tons per acre are occasionally obtained on these soils. Commercial fertilizers alone will not produce such high yields, a fact which emphasizes the need of a well-rounded soil-building program for best results.

SOILS INTERMEDIATE BETWEEN MINERAL AND PEAT

Intermediate between true mineral and peat soils are several that are high in organic matter; these soils may include some peaty sublayers, which contain comparatively large quantities of fine-textured mineral sediment. This sediment is usually well mixed with organic remains, but may occur in thin layers separating more highly organic layers. Representative of these is the Ryde series, of which Ryde clay loam is the dominant type used for sugar-beet production. These soils are subject to high water table, which must be adequately controlled. In general they have an abundance of nitrogen and show no response to this element in fertilizers. They are usually acid in reaction, and many fields tested have proved much too acid for good beet production. Where tests show a reaction below pH 5.5, one should apply lime before attempting to grow beets.

TABLE 11

RESULTS OF FERTILIZERS WITH AND WITHOUT LIME ON RYDE CLAY LOAM, 1938

Treatment	Rate per acre*				Gross sugar per acre	Beets per acre	Sucrose
	N	P_2O_5	K_2O	Lime			
	pounds	*pounds*	*pounds*	*tons*	*pounds*	*tons*	*per cent*
Ammonium phosphate (16–20–0) plus lime.	35	45	0	5	6,376	20.67	15.46
Ammonium phosphate (16–20–0)..........	35	45	0	0	6,159	19.47	15.52
Treble superphosphate plus lime.........	0	80	0	5	7,256	21.56	16.82
Treble superphosphate....................	0	80	0	0	6,592	20.37	16.11
Mixture plus lime.........................	0	35	45	5	6,929	20.96	16.47
Mixture..................................	0	35	45	0	6,449	20.22	15.91
Lime.....................................	0	0	0	5	5,918	18.10	16.27
Untreated soil............................	0	0	0	0	5,630	17.39	16.15
Difference between treatments required for significance*........................	..	..	..	..	976	1.84	1.26

* See footnotes to table 3.

In 1938 an experiment was conducted on a field of Ryde clay loam, in which fertilizers were tried with and without lime in combination. The soil varied in reaction over different parts of the field, but averaged about pH 6.0. Plots were made about ¼ acre each in size and were replicated six times. The results appear in table 11.

Judging from these data, the response in yield was attributable primarily to the phosphorus portion of the fertilizer. Neither nitrogen nor potash

seemed to lend any additional value. No significant difference was noted in sucrose percentage, although the nitrogen in the 16–20–0 fertilizer caused a trend toward lower sucrose. This trend was further reflected in the gross sugar yield from these treatments.

In all plots the addition of lime slightly increased the yield of beets over similar fertilization without the lime. This increase averaged only 0.92 ton

TABLE 12

Results of Varying Amounts of Phosphate on Ryde Silty Clay Loam, 1939

Treatment	Rate per acre*			Gross sugar per acre	Beets per acre	Sucrose
	N	P_2O_5	K_2O			
	pounds	*pounds*	*pounds*	*pounds*	*tons*	*per cent*
Treble superphosphate	0	60	0	7,378	21.33	17.27
Treble superphosphate	0	120	0	7,666	20.71	17.30
Treble superphosphate	0	180	0	7,424	21.17	16.77
Complete fertilizer	50	60	50	7,594	22.25	16.69
Untreated soil	..	..	..	4,792	13.90	16.46
Difference between treatments required for significance*	..	..	..	1,121	3.17	0.55

* See footnotes to table 3.

TABLE 13

Results of a Placement Study with Treble Superphosphate on Ryde Clay Loam, 1940

Placement of fertilizer	Rate of P_2O_5 per acre*	Gross sugar per acre	Beets per acre	Sucrose
	pounds	*pounds*	*tons*	*per cent*
Midway between rows, 6 inches deep	50	6,041	18.55	16.55
Midway between rows, 4 inches deep	50	5,844	17.54	16.69
Midway in alternate spaces between rows, 6 inches deep	50	5,996	17.59	17.08
Unfertilized soil	..	5,094	15.04	16.95
Difference between treatments required for significance*	..	930	2.56	0.52

* See footnotes to table 3.

per acre which was not significant. The pH of the soil was only about 6.0, however, not an extremely acid condition.

The lime effect was further illustrated in another field of Ryde clay loam soil in 1938. Lime was applied at rates of 2½, 5, and 10 tons per acre, in small plots replicated five times in Latin-square arrangement, results of which were not tabulated. Increased yields from the lime ranged from 1.6 to 3.0 tons per acre. Under the conditions of this experiment 2.6 tons of beets per acre were required for a significant difference. Where phosphate was used with lime there was a marked significant increase in yield, with no depression in sucrose percentage.

On a field of Ryde silty clay, shallow phase, an experiment was conducted in 1939 to determine how much phosphate could be profitably used on this soil. Plots were made about 1 acre each in size and were replicated three times. The results appear in table 12.

Under the conditions of this experiment the results indicate that 60 pounds of P_2O_5 were as beneficial as any larger quantity. There appeared, however, to be a definite need of phosphate; and the increase in yield was very marked, averaging about 7 tons per acre, with no loss in sugar percentage. As in the previous trial, there was no indication of any benefit from either potash or nitrogen, as determined from comparing the complete fertilizer treatment with a similar quantity of P_2O_5 alone.

In 1940 an experiment was conducted on Ryde clay loam in which three methods of phosphate placement were studied. Treble superphosphate was used as a fertilizer at the rate of 50 pounds of P_2O_5 per acre. Placements were as follows: (1) midway between rows at 6-inch depth, (2) midway between rows at 4-inch depth, and (3) midway in only alternate spaces between rows at 6-inch depth. There was also one unfertilized check. Plots were made about ⅖ acre each in size and were replicated four times in Latin-square arrangement. The results appear in table 13.

The data show a significant increased yield of beets due to the fertilizers, with a trend suggesting that the deeper placement in each between-row space was preferable. Yield increases due to phosphate were somewhat less than had been obtained on a similar soil the previous year. As stated above, this soil type is extremely variable in organic-matter content. Judging from field observations and experiments, the more peat contained in the sample, the less the need for phosphorus.

PEAT OR MUCK SOILS

Several thousand acres of sugar beets are annually produced on the peat and muck soils of the Sacramento–San Joaquin Delta, and their fertilization presents many perplexing problems. These soils vary greatly in depth of organic remains, state of decomposition and weathering, proportion of organic matter to sediment, height of water table, reaction, salinity, and other factors. Some areas exhibit evidence of an overabundant supply of nitrogen, and others similarly located show extreme nitrogen deficiency. In general there seem to be no well-defined physical characteristics on which to differentiate their behavior.

Beets with field averages at harvest time of as low as 8 or 9 per cent sucrose, and individual samples as low as 3 or 4 per cent, have frequently been reported. Usually under such conditions the tonnage yield has been satisfactory. In contrast is the also frequent occurrence of beets with a sucrose content of 18 + per cent but with tonnage yields as low as 8 or 10 tons per acre. Either situation is undesirable. It seems difficult to forecast which may be encountered. Previous cropping history offers some suggestions, but leaves many questions unanswered. The areas of abnormally low sucrose most often followed a crop of potatoes, which in turn had been preceded by controlled burning. One effect of burning that seems pertinent is to shift the reaction of the surface soil toward the alkaline side.

Fertilization problems therefore involve the question of increasing the tonnage yield in some areas and improving the sucrose percentage in others. Where the situation is due to an insufficient supply of available nitrogen, it can be easily remedied by the use of commercial nitrogen fertilizers. Since

however, there is an abundance of organic nitrogen in all these soils, a more lasting remedy would seem to lie in cultural practices that will promote natural nitrification.

In studies on peat soils in laboratory and greenhouse, available soil nitrogen was markedly increased by the incorporation of finely divided green plant material at a rate of about 10 tons per acre, together with sufficient moisture but no waterlogging. The same result can be effected with smaller amounts of barnyard manure.

MAJOR ELEMENTS IN PEAT SOILS

Where the situation results from an excessive supply of available nitrogen, the problem is difficult. One general assumption has been that where an excessive nitrogen supply tended to depress sucrose synthesis, the difficulty was due to an unbalanced nutrition. Conceivably, under such circumstances, the situation might be corrected by increasing the supply of other plant food elements in order to place them in "balance" with the nitrogen. On this assumption, numerous field trials were made on various locations where abnormally low sucrose had been previously reported. In 1934 one such trial was conducted on King Island, on a soil since classified as Egbert muck (*3*). Beets produced on this area in 1933 were reported as containing about 9 per cent sucrose, with over 30 tons per acre yield. Fertilizers for this experiment were placed about 5 inches deep in a 4-inch band directly under the row and just ahead of the beet planter. The soil between the fertilizing and planting operations was made firm with a heavy roller. Plots were made about 1/60 acre each in size and were replicated eight times. Fourteen different treatments were used. The results appear in table 14.

TABLE 14
Results on Egbert Muck, with Fertilizers Placed Below the Seed at Planting Time, 1934

Treatment	Rate per acre*			Beets per acre	Sucrose
	N	P_2O_5	K_2O		
	pounds	*pounds*	*pounds*	*tons*	*per cent*
Treble superphosphate	0	50	0	17.6	17 12
Mixed fertilizer	0	50	75	19.9	17.04
Potassium sulfate	0	0	50	20.6	17.36
Complete fertilizer	33	50	33	20.9	17.28
Superphosphate	0	150	0	20.2	17.50
Treble superphosphate	0	150	0	21.7	17.54
Mixed fertilizer	0	150	225	20.8	17.38
Potassium sulfate	0	0	150	19.7	16.87
Complete fertilizer	100	150	100	19.0	17.69
Treble superphosphate	0	300	0	21.8	16.97
Mixed fertilizer	0	300	450	21.3	16.86
Potassium sulfate	0	0	300	20.2	17.13
Complete fertilizer	200	300	200	20.8	17.12
Unfertilized soil	..	..	..	19.8	17.54
Difference between treatments required for significance*	..	..	..	2.87	0.57

* See footnotes to table 3.

In this field no nitrogen-deficiency symptoms were observed; and, as the data reveal, there was no marked deficiency in sucrose percentage. The fertilizer treatments had no effect that could be discerned.

In later trials, with identical treatments used on three locations (two on Staten peaty muck and one on Egbert muck), treble superphosphate and potassium sulfate were broadcast at the rate of 1,000 pounds per acre, before planting. Superimposed on these basic treatments were side dressings of several forms of mixed complete fertilizers. Yields on these locations ranged from 22 to 30 tons per acre, and none of the treatments used had any effect on either the yield or the sucrose percentage.

TABLE 15

RESULTS OF LUXURY AMOUNTS OF FERTILIZERS ON STATEN PEATY MUCK, 1938

Treatment	Rate per acre*			Gross sugar per acre	Beets per acre	Sucrose†
	N	P_2O_5	K_2O			
	pounds	*pounds*	*pounds*	*pounds*	*tons*	*per cent*
Mixed fertilizer	0	1,200	1,500	6,721	26.1	12.9
Treble superphosphate	0	2,700	0	7,247	25.7	14.1
Superphosphate	0	2,700	0	6,384	26.8	11.9
Complete fertilizer	800	800	800	7,706	31.1	12.4
Treble superphosphate	0	450	0	6,623	25.5	13.0
Untreated soil	..	.....	.....	7,353	24.7	14.9
Difference between treatments required for significance*	..	.....	.....	.....	4.04	....

* See footnotes to table 3.
† Sucrose percentages were obtained from a composite sample of all replications.

TABLE 16

RESULTS OF PHOSPHORUS, NITROGEN, AND A COMPLETE FERTILIZER ON STATEN PEATY MUCK, 1939

Treatment	Rate per acre*			Gross sugar per acre	Beets per acre	Sucrose
	N	P_2O_5	K_2O			
	pounds	*pounds*	*pounds*	*pounds*	*tons*	*per cent*
Treble superphosphate	0	65	0	2,503	8.15	14.82
Cal-Nitro	60	0	0	4,373	14.34	15.76
Complete fertilizer	17	22	21	2,432	8.60	14.40
Untreated soil	..	..	..	2,536	9.22	16.09
Difference between treatments required for significance*	..	..	..	1,678	4.22	4.01

* See footnotes to table 3.

In 1938 a field trial was conducted in which fertilizers were applied as side dressings in very large amounts, in single-row plots $\frac{1}{1000}$ acre each in size, replicated 10 times. The fertilizers were applied in a trench about 8 inches deep at the side of the rows at thinning time. The results appear in table 15.

A difference of 4.04 tons per acre was required for significance in this experiment, and only the complete fertilizer produced an effect of this magnitude. The only noticeable trend, in fact, was a slightly higher tonnage yield with

the heavy nitrogen treatment. Clearly, according to the foregoing experiments, one cannot increase the supply of phosphate or potash to "balance" the nitrogen and obtain the desired results.

In 1939 a location was selected in which nitrogen-deficiency symptoms had previously been apparent. The soil was Staten peaty muck, and fertilizers were applied at thinning time as side dressings. Plots were made about 1 acre each in size and were replicated three times. The results are shown in table 16.

Nitrogen appeared to be the main limiting factor in this soil, and the Cal-Nitro fertilizer treatment definitely increased both tonnage and gross sugar per acre. The small amount of nitrogen in the complete fertilizer gave an early response to top growth, as indicated by field observations; but the

TABLE 17

Results of Phosphorus Treatments on Egbert Muck, 1940

Treatment	Rate per acre*		Gross sugar per acre	Beets per acre	Sucrose
	N	P_2O_5			
	pounds	*pounds*	*pounds*	*tons*	*per cent*
Treble superphosphate	0	65	9,072	24.92	18.21
Treble superphosphate	0	130	9,067	23.98	18.87
Ammonium phosphate (16–20–0)	25	30	9,268	25.45	18.19
Ammonium phosphate (16–20–0)	12	55	8,772	23.16	19.04
Untreated soil	..	..	9,242	24.45	18.91
Difference between treatments required for significance*	..	..	929	2.28	1.08

* See footnotes to table 3.

response was temporary and did not affect the final yield. Neither the phosphate nor potash seemed to have any noticeable effect.

In another experiment on Egbert muck in 1940, some further trials were made of phosphate fertilizers side-dressed for beets. Plots measured about 1 acre each and were replicated three times. The results appear in table 17.

As the data indicate, there was no appreciable effect from any of the fertilizer treatments, offering further evidence that phosphorus and/or potash were not effective on this soil. Nitrogen deficiency had not been evident in this soil; the tonnage yields were reasonably high, as was also the sucrose percentage.

The four experiments listed above for peat soils show the general trend of results as secured in many other experiments. On areas deficient in available nitrogen, through lack of natural nitrification, a temporary remedy is the use of commercial nitrogenous fertilizers. Drainage, aeration, cultivation, liming to decrease the acidity, and the incorporation into the soil of readily decomposible organic matter to stimulate nitrification will alleviate the difficulty from lack of available nitrogen. On those soils where an excessive nitrogen supply is the detrimental factor, the solution definitely does not lie in the use of commercial phosphate or potash. The most satisfactory remedy for this situation would seem to consist in changing the cultural practices so that the beets would come in a different place in the rotation—for example, following a grain or milo crop.

MINOR ELEMENTS IN PEAT SOILS

Peat soils of other areas in the country are not infrequently deficient in one or more minor elements. This condition so far has not been demonstrated for the peat and muck soils of the Sacramento–San Joaquin Delta. In a 1934 experiment on Egbert muck and Staten peaty muck, boron, copper, manganese, and magnesium were applied as side dressings to small plots of beets. No growth effect was noted from any of these materials. In 1939 about 100 individual beets were selected in various fields and treated with some one of the materials just mentioned. These beets were carefully observed for any change in appearance. None was observed for any of the treatments tried.

CONCLUSIONS

In the Sacramento Valley area, sugar-beet production is restricted chiefly to mineral soils of the Yolo, Sacramento, and Columbia series and muck or peat of the Ryde, Egbert, and Staten series. Minor acreages are on other soils.

Intelligent use of commercial fertilizers by the grower necessitates a selection of the proper fertilizer for the soil. Further, it necessitates consideration as to timeliness of the application, correct placement of the fertilizer material with respect to plant roots, and the use of reasonable amounts.

All strictly mineral soils investigated have some common characteristics in their response to fertilizer. They have not responded to the use of either phosphorus or potash under any of the conditions where these materials were tried. Whether or not these soils show an appreciable response to nitrogen depends upon the degree to which the natural fertility has been depleted. Where the fertility level has become very low, up to 120 or 150 pounds of nitrogen per acre may be economically used to restore yields. To supply this quantity of nitrogen will require 600 pounds or more of material containing 20 per cent nitrogen. Progressively, as the natural fertility is higher, the need for commercial nitrogen will be lower.

Where nitrogen is required, the first increment of 40 or 50 pounds per acre can be expected to increase yields 3 to 5 tons of beets per acre. On very low-yielding soils an additional 40 to 50 pounds per acre can be expected to increase the yield further by 2 or 3 tons. In extreme cases a third increment of a like amount of nitrogen will provide an additional increase of 2 tons.

Nitrogen fertilizers on beets tend to delay maturity; and where the nitrogen supply is not entirely utilized, a slight depression in sucrose percentage may occur. A long growing season with delayed harvest tends to offset this condition. If extremely large amounts of nitrogen are used, the depression in sucrose synthesis may be sufficient to counteract all the benefits of increased yield.

Yields up to about 25 tons of beets per acre may be obtained on these soils by correct use of commercial nitrogen. Occasionally, yields may be higher than this. To obtain such results requires a general soil-building program, involving not only the chemical phase of the soil but also the physical features.

Timeliness of the application is important. Nitrogen-bearing fertilizers cannot be safely applied with the seed. Some growers customarily plow the fertilizer under so that it is placed in a band directly beneath where the beet

row is to be planted. This practice, though satisfactory in many respects, might prove wasteful if reseeding or other cropping were necessary.

Nitrogen applied too late in the season will not all become available to the plants before harvest, and may unduly delay maturity. In this respect a nitrate form of nitrogen can be applied somewhat later than an ammonia or urea form. An application at about thinning time has proved generally successful. If a heavy rate of nitrogen is needed, somewhat better results will be obtained by splitting the application, using one half at thinning time and the other during the period of greatest foliar production.

Correct placement necessitates putting the fertilizer material in moist soil and within easy reach of the plant roots. Obviously, then, the depth must be below the zone of rapid surface evaporation. The distance from the plant can vary according to the age of the plant. At the thinning stage it should be within 3 or 4 inches, to the side. For later applications, 10 to 12 inches are entirely satisfactory.

Strongly acid soils of pH 5.5 or less, as in the Ryde series, are not satisfactory for beets without previous liming to reduce the acidity. These same soils can generally be regarded as deficient in phosphate. Normally they do not respond to nitrogen.

Most of the peat soils of the Delta were originally acid in reaction. Surface burning of peat soils is, however, a common practice. It results in the deposition of an alkaline ash, which has the same effect as liming. Consequently, much of the peat-soil area is now only slightly acidic to slightly alkaline. Trials with phosphate or potash have generally been ineffective in improving beet growth.

These peat soils vary widely in their ability to supply nitrogen to crops. All peats contain large quantities of stored nitrogen per acre foot of soil. Thus when conditions are favorable for decomposition of the peat, there may be an excessive supply of available nitrogen. On the other hand, there are also frequent situations where a deficiency of available nitrogen has resulted from lack of sufficient decomposition. When this occurs the grower may decide, as a temporary measure, to supply nitrogen in commercial fertilizer. A more permanent remedy lies, however, in stimulating decomposition of the peat. This can be done by incorporating into the soil some readily decomposible organic matter such as green covercrops. It can also be done by applying small quantities of barnyard manure. Where the available nitrogen supply is excessive, some control can be secured by using nitrogen-depleting crops to precede the beets. Milo is especially active in this respect, because of the sugary root residues remaining in the soil.

SUMMARY

Greenhouse tests with Yolo loam soil demonstrated that all nitrogen-carrying fertilizers, when placed either in contact with the seed or in close proximity, strongly depressed germination of the seed balls. Phosphate fertilizers depressed germination somewhat less, but were injurious. For protection, 1 inch of soil separating seed from fertilizer was insufficient.

Beet seed planted 2½ inches deep germinated only 30 per cent as well as seed planted only 1½ inches deep.

Field experiments were conducted on a number of fields on mineral soils of the Yolo, Sacramento, Columbia, and Conejo series. On these mineral soils, nitrogen was the only fertilizer that improved production of beets. Increases in yields on these soils varied from 10 tons per acre down to nothing, according to the degree to which the natural soil fertility had become depleted.

Sucrose percentages were only slightly depressed by moderate amounts of nitrogen fertilizers.

Experiments on soils of the Ryde series showed that yields can generally be much improved by the use of phosphate fertilizer. Often, additional improvement may result from liming.

Muck and peat soils such as the Egbert, Staten, or Venice series showed no benefit from phosphate or potash for sugar-beet production. Where growth on these soils was depressed from a shortage of nitrogen, yields were improved through the use of nitrogen fertilizers. Where an excessive supply of available soil nitrogen caused an unnatural growth, with greatly depressed sucrose synthesis, no fertilizer practice seemed to benefit the situation. A change in rotation practice is suggested as a possible remedy.

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